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ABSTRACT

In most european countries, Ground Source Heat Pumps (GSHP) are installed mainly in new houses. The main barriers for installation of GSHP on retrofit market are linked to the installation process and costs of ground heat exchangers.
This study evaluates the impact and sizing of two types of ground collectors, potential best solutions for retrofit market, partly by using a specific GSHP modelling tool. This leads to the determination of a ground collectors system adapted to the retrofit market, consisting in 50 meters depth borehole heat exchangers.
In a second part, the paper presents an analysis of solar ground reloading influence on GSHP sizing, global performances and costs, using the same modelling tool.
In conclusion, this paper shows that 50 meters depth borehole heat exchangers associated with solar ground reloading system is an interesting technological solution, but doesn't always meet retrofit market requirements in term of compacity and costs.

1. INTRODUCTION

In Europe, the residential retrofit market has the most important size - 80% of the houses that will be used in 2050 in France already exist - and represents the main source of energy consumption in buildings. Then, the energy consumption reduction in existing buildings, by using renewables for heating and cooling has become a major stake in Europe.
Despite this favorable context and a fast growing success in new houses (around 113 500 units sold in Europe in 2006, +40% compared to 2005[1]) , GSHP are mostly absent from the residential retrofit market in Europe (except in Sweden and Switzerland). The main identified barriers to the development of GSHP in european existing houses are the ground collectors installation (process and costs) and the needed area in gardens, already made-up.
Then, this paper describes an analysis of two types of ground heat exchangers, potential good solutions for existing houses, and the influence of a solar ground reloading strategy on the global impact of GSHP.
The objective is to characterize the best available solution of GSHP for the residential retrofit market and to evaluate if this present solution is totally adapted to this market constraints.

2. INSTALLATION OF GROUND COLLECTORS IN OLD HOUSES

Ground collectors represent the critical constraint of GSHP in old houses, for several reasons.

[1] figures gathered and validated by EDF R&D from several sources : European Heat Pump Association (EHPA), Building Services Research and Information Association (BSRIA) mainly

Old houses in Europe are often badly insulated houses with small make-up garden (few hundred square meters). For example, the average size on the garden in existing houses in France is 500-600 m^2, in the shape of square. This area comprises trees, vegetable garden, terrace and drive to a car garage. The effective free area in made-up french garden rarely exceeds 200-250 m^2, in several parts.
The installation of GSHP induces a large and expensive sizing of ground heat exchangers, not necessarily compatible with the size and the configuration of garden explained above. Moreover, the damages caused in the garden by the installation process are important.
In this part are presented or reminded two types of ground heat exchangers that seem to minimize their global impact on the garden : vertical borehole heat exchangers, of course, and new "compact collectors".

2.1 Compact collectors

The compact collectors have been developed by a swedish manufacturer (Wärnelöf,2005) with the objective of reducing the installation costs. These modular collectors are built in PEM, Poly Ethylene. They consist in a number of 40 mm pipes connected with U-bends at the top and at the bottom (figure 1). Each module has the dimensions 1500x2000 mm (width x height). Up to ten modules can be connected in series[2].

Figure 1 : compact collector (IVT photo)

The compact collectors can be installed in two ways : vertically or horizontally (figure 2).

- For the vertical installation (preferred and most compact), the modules are put in 3 meters depth trenches (0.5 to 1 m width). The spacing between to trenches has to be at least 3 meters.
- For the horizontal installation (wet or sliding ground conditions), the collectors are put at 1.5 to 2 m depth with the connections slightly higher than the bottom of the module.

In both cases, the soil has to be filtered before re-introduced around the compact collectors to prevent rocks from damaging the collectors. Another solution is to replace the soil by sand.

Figure 2 : installation of compact collectors (EDF and IVT photos)

[2] The compact collectors are commercialized in Sweden (often for low energy houses) with a heat recovery unit, consisting in an exhaust air / brine exchanger connected in serie with the ground collectors. This auxiliary unit needs a mechanical ventilation system with a quite high air flow (~400 m3/h) and can not be installed in most old european houses.

The compact collectors, possibly installed in narrow and modular trenches, can be interesting for the residential retrofit market ; most of houses having very small available garden areas.
However, the installation process consisting in drilling and filling up, with filtered soil, 3 meters depth trenches, is very difficult and tedious. Each trench represents at least 300 m^3 of soil to move and filter (or to evacuate and replace by sand). Then, the number of trenches has to be limited at 2 for a residential installation.

2.2 Low depth Borehole Heat Exchangers (BHE)

Among the classical ground heat exchangers, shallow horizontal collectors or borehole heat exchangers (BHE), the BHE seem to be more adapted to the retrofit market constraints : the horizontal collectors, such as the horizontal installation of compact collectors, imply the destruction of several hundred square meters of make-up garden to be installed.

However, the common BHE are also uneasy to install in an old house because of the size of the drilling rig, that causes damages in the garden (figure 3).
This type of drilling rig, with a size of a medium truck, is necessary to drill BHE of 100 to 150 meters depth, which is the common depth of BHE in Europe.
But, to be valuable in old houses, BHE have to be installed with a drilling rig much more compact than rigs usually used. The solution can come from a change in the depth of BHE. By limiting the depth of BHE at 50-60 meters, it is possible to use compact and easily transportable drilling rigs (figure 3, width of 1-1,2 meter, weight of 2-2500 kg). This compact type of drilling rigs is commonly used for geotechnical drilling.

Figure 3 : drilling rigs for a depth of 100-150 m (left, www.ader.ch) and about 50 m (right, EDF photo)

The obvious consequence in case of reduction of the boreholes depth is the corresponding increasing of the number of boreholes necessary to supply the same energy. But, we saw in §2, for known data in Europe, the average free area in made-up gardens rarely exceeds 200-250 m^2, in several parts. In these gardens, the number of boreholes can't exceed 4, taking in account a boreholes spacing of 10 meters and a spacing to obstacle (tree, wall, etc.) of 3 meters.

3. SIZING OPTIMIZATION OF GSHP IN OLD HOUSES

In the previous paragraph, two types of ground collectors have been found interesting regarding the individual retrofit market constraints, but only if their sizing can be limited.
In this paragraph, the sizing of these two types of ground collectors is studied, for different old houses cases. This study is made, thanks to a GSHP modelling tool developed by *Ecole Polytechnique de Montréal*.

3.1 GSHP modelling tool and studied parameters

A first version of the modelling tool, developed in 2003, is dedicated to the borehole heat exchangers (BHE) sizing. This version is based on the thermal response of the ground near the BHE at three thermal impulses of different time orders (hour, month and year) (Bernier, 2006). For a specific building (with specific hourly needs[3] and functioning characteristics of the heat pump), the necessary length of BHE is determined to minimize the correction of temperature of the ground over a chosen period of use of the BHE (generally 10 to 20 years), according to the following equation (Bernier, 2006) :

$$L = \frac{q_h R_b + q_y R_y + q_m R_m + q_h R_h}{T_g - T_f} \tag{1}$$

where L is the borehole length, q_h, q_m and q_y represent ground loads whith h, m and y to the three hourly, monthly and yearly thermal pulses. R_y, R_m and R_h (m.K/W) represent effective thermal resistance for each thermal pulse. R_b is the thermal resistance in the borehole. T_g represents the far field ground temperature and T_f the minimum mean brine temperature in the BHE.

A second version of this software, used for this study, has the same principle. It is also based on the thermal response of the ground at the same thermal pulses.
The evolution is that the software, besides calculating a BHE length, determines the best configuration of compact collectors to minimize the correction of ground temperature, for a given installation.
The impact of compact collectors configurations on the ground is calculated thanks to g-functions (Eskilson,1987).
This software has a library of 21 g-functions corresponding to 21 different configurations of compact collectors with various numbers of trenches (1 to 5), various numbers of modules per trench (8 to 10) and two different spacing between the trenches (3 or 5 meters).

For this study, this software is used to determine and compare the necessary sizing of compact collectors and BHE for several houses heated areas and various climatic and geological conditions.
More precisely, the ground collectors sizing has been evaluated for :

- three different houses areas - 110, 150 et 200 m^2 - with an average insulation level for 30 years old houses (volumetric loss factor G = 1,2 W/m^3.K)
- three different climatic localisations : base outside temperature = -15°C, heating degree days = 2976
  base outside temperature = -5°C, heating degree days = 2670
  base outside temperature = -2°C, heating degree days = 2211
  The heating degree days are considered with a comfort temperature of 19°C. These climatic conditions correspond to Strasbourg (France, continental climate), Rennes (France, oceanic climate) and Nice (France, mediterranean climate)
- three very different geological conditions : dry clay (λ =1,2 W/m.K, α = 0,054 m^2/day, ρ = 1925 kg/m^3)
  humid shale (λ =1,9 W/m.K, α = 0,075 m^2/day, ρ = 2350 kg/m^3)
  saturated sand (λ =3,3 W/m.K, α = 0,097 m^2/day, ρ = 1925 kg/m^3)

The table 1 describes the heating needs / extracted energy from the ground[4] for each climate and each house size.

Table 1 : Heating needs / Extracted energy for each simulated case (kW)

Climate / House area	Continental	Oceanic	mediterranean
110 m^2	10,0 / 7,2	8,4 / 6,1	7,5 / 5,4
150 m^2	13,7 / 9,9	11,5 / 8,3	10,2 / 7,4
200 m^2	18,2 / 13,1	15,3	13,6 / 9,8

3.2 Optimized configurations of compact collectors

Here are presented the results of the software simulations for the compact collectors. In the three tables below, we can see, for each simulated house heated area, the needed compact collectors configuration depending on the climate

[3] meteorological datad files, with temperature and sunniness (solar energy by square meter), are available for about 15 locations mainly in France.
[4] taking in account heat pump performances : Coefficient of Performance (COP) of 3,6 with brine temperature at the evaporator inlet of 0°C (B0) and COP = 4,5 at B10

and the geological conditions. The results given in the tables are the number of trenches multiplied by the number of modules. The trench spacing is chosen at 5 meters, to limitate the thermal interference between the trenches.

Table 2 : Software results for the 110 m^2 house and compact collectors

Soil \ Climate	Continental	Oceanic	mediterranean
dry clay	5 x 9	4 x 9	4 x 8
humid shale	3 x 10	3 x 8	3 x 8
saturated sand	2 x 10	2 x 8	2 x 7

Table 3 : Software results for the 150 m^2 house and compact collectors

Soil \ Climate	Continental	Oceanic	mediterranean
dry clay	> 5 x 10	5 x 10	5 x 9
humid shale	4 x 10	4 x 8	3 x 10
saturated sand	3 x 9	3 x 8	2 x 9

Table 4 : Software results for the 200 m^2 house and compact collectors

Soil \ Climate	Continental	Oceanic	mediterranean
dry clay	> 5 x 10	> 5 x 10	> 5 x 10
humid shale	5 x 10	5 x 9	4 x 10
saturated sand	4 x 9	3 x 9	3 x 8

We can notice the influence of the geological conditions. The extracted energy by module is about 170 W for dry clay, 240 W for humid shale and 380 W for saturated sand, whatever the climate is.

In much cases, the sizing of compact collectors, necessary to meet the heating needs of an old house, is quite higher than a reasonable installation in an average made up garden.
Except for particular conditions, at least 3 or 4 trenches of modules are necessary, whereas two trenches can be considered as a maximum, taking in account the installation process.

In conclusion, these compact collectors, sized to cover 100% of the energy needs, are not a valuable solution, in term of sizing and dimensions, for the european residential retrofit market.

3.3 Optimized length of BHE

The three tables below indicate the software results in term of borehole heat exchangers length (number of BHE x depth, in meters) in the predefined simulation conditions.
For these simulations, a double U-tubes configuration is chosen, associated with a high conductivity (λ =2,0 W/m.K) grouting.

Table 5 : Software results for the 110 m^2 house and BHE (m)

Soil \ Climate	Continental	Oceanic	mediterranean
dry clay	7 x 50	5 x 50	4 x 55
humid shale	**5 x 45**	**4 x 45**	**3 x 50**
saturated sand	3 x 50	3 x 45	2 x 55

Table 6 : Software results for the 150 m^2 house and BHE (m)

Soil \ Climate	Continental	Oceanic	mediterranean
dry clay	9 x 55	7 x 50	6 x 50
humid shale	**6 x 55**	**5 x 50**	**4 x 55**
saturated sand	5 x 45	4 x 45	3 x 50

Table 7 : Software results for the 200 m^2 house and BHE (m)

Climate / Soil	Continental	Oceanic	mediterranean
dry clay	12 x 55	10 x 50	8 x 50
humid shale	**9 x 50**	**8 x 45**	**6 x 50**
saturated sand	6 x 50	5 x 45	4 x 50

Three very different geological conditions have been tested in order to compare with the 3 meters depth trenches of compact collectors. However, over 50 meters in depth, a borehole heat exchanger is in contact with several layers of various soils. Then, the average thermal conductivity of the ground is often close to 2 W/m.K , and can vary in a thin interval of 1,5 to 2,5 W/m.K, depending on the humidity level of the ground. This average conductivity corresponds, in the tables above, to humid shale ground.
Then, these tables shows that a limited number of boreholes heat exchangers is able to cover the heating needs of a small (110 m^2) old house .
In some other cases, the number of boreholes is limited to 5 or 6. If 5 or 6 boreholes can be problematic for a typical european garden, a solution can be found by adding a auxiliary system that could eventually permit to reduce the heat exchangers sizing.

4. SOLAR GROUND RELOADING

The association of Ground Source Heat Pumps with solar collectors is often evocated (Trillat-Berdal, 2006), (Kjellson, 2007). The main scheme consists in a functional distribution, GSHP providing heating and the solar collectors providing hot water. More and more often, ground and solar collectors can be directly associated. When hot water needs are satisfied, brine heated in the solar collectors circulates directly in the ground collectors, which constitutes a thermal ground reloading.
This solar ground reloading is often studied with an objective of global performances optimization or ground temperature recovering in cold regions.

4.1 Influence on sizing
Few studies have been dedicated specifically to the impact of solar ground reloading on the ground collectors sizing and its potential gain.
Based on the equation (1), M.Bernier (Bernier, 2007) shows by modelling that the peak ground load is responsible for about 65% of the BHE sizing, the monthly load (often considered as the coldest month of the heating season) for 20 to 25%, the annual ground load representing 10 to 15% of the sizing. As solar energy is available mainly in summer, it can have a significant effect only on the annual ground load. Its impact on the ground collectors sizing is probably limited to 10 or 15%, corresponding to the part of annual ground load in the sizing.

The software previously used to compare the two types of ground collectors is able to take in account the impact of a solar ground reloading system on ground collectors sizing. For each hour of the year, it calculates the correction in the heating extraction from the ground, by evaluating the solar energy that can be re-injected, according to the scheme shown on figure 4.

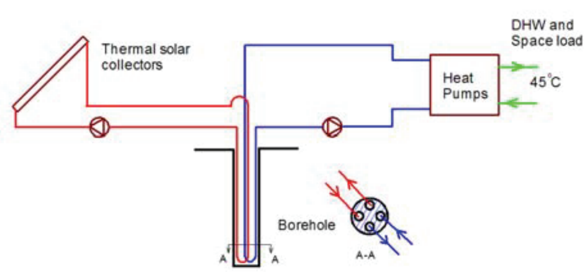

Figure 4 : Solar ground reloading principle

Then, this software was used to evaluate the gain in sizing that can be obtained by associating several areas of solar collectors with ground collectors. As the compact collectors sizing is not adapted to the european retrofit market, which is our concern, only borehole heat exchangers were evaluated, associated with solar collectors, in this study.
The following simulation conditions were imposed :

- same three climatic conditions as previous study ones,
- three house areas, 110, 150 and 200 m^2 with the same insulation level as previously (G=1,2 $W/m^3.K$) ;
- average geological conditions (cf previous paragraph) : humid shale (λ =1,9 W/m.K, α = 0,075 m^2/day, ρ = 2350 kg/m^3) ;
- two different solar collectors areas : 5 and 10 m^2 (horizontal position) .

The two tables below indicate the results in term of ground collectors sizing (number of BHE x depth, in meters). In parenthesis is indicated the sizing reduction in percents, compared to the initial sizing with BHE alone.

Table 8 : Software simulation results for BHE associated with 5 m^2 of solar collectors

Climate / House area	Continental	Oceanic	mediterranean
110	4 x 50 (11%)	3 x 52 (13%)	3 x 40 (20%)
150	6 x 50 (9%)	5 x 45 (10%)	4 x 45 (18%)
200	9 x 46 (8%)	6 x 55 (8%)	6 x 42 (16%)

Table 9 : Software simulation results for BHE associated with 10 m^2 of solar collectors

Climate / House area	Continental	Oceanic	mediterranean
110	4 x 46 (18%)	3 x 48 (20%)	2 x 50 (33%)
150	6 x 46 (16%)	4 x 52 (17%)	3 x 51 (30%)
200	8 x 49 (13%)	6 x 51 (15%)	4 x 55 (27%)

The contribution in term of solar energy is, of course, constant for given location and solar collectors surface. However, the impact on ground collectors sizing, in meters, is growing with the numbers of boreholes, thanks to the thermal interference between collectors which is favorable in case of heat injection in the ground ; even if in percentage, the impact is more important for the small BHE fields.
Nevertheless, except for particular mediterranean conditions, the solar ground reloading impact is limited to 13 - 20%. It's little more than evaluated by M.Bernier (Bernier, 2007) : the solar reloading can possibly have a little impact on the monthly ground load.
Then, solar ground reloading can offer a solution in some cases in sunny or temperate regions. It does not permit to radically reduce the sizing of BHE in order to make them valuable in most retrofit installations.

4.2 Influence on installation costs

An other critical point in the installation of GSHP in an old european house is the installation costs.
The low average insulation level on retrofit market induces high heating needs and then a important sizing of ground collectors.
For instance, in France, the global investment (supplying and installation) costs for a GSHP (equipped with BHE) in an old average (110 - 150 m^2) house is about 20000 to 30000 €[5] (30000-45000 US$). 50 to 60% of this global cost are due to the borehole heat exchangers.
The average cost of one meter of BHE is 80 €/m (120 US$), including borehole drilling, collector installation and connecting to the heat pump.
Then, reducing the sizing of BHE for an average house by installing 10 m^2 of solar collectors could permit to reduce the ground collectors costs of 2500-3500 € (3700-5200 US$). Well, solar collector cost, without installation is about 350 €/m^2, that is to say 3500 € (5200 US$) for the needed area, without installation.
Therefore, in most cases, a solar ground reloading system make the global costs of a GSHP increase, whereas the GSHP cost is already a brake to its development, particularly on retrofit market.

[5] All costs are considered with VAT excluded.

5. CONCLUSIONS

GSHP hardly develop on european residential retrofit market, because of the difficulties to install and the costs of their ground heat exchangers.
Using a specific modelling tool, this paper shows that, among the existing ground collectors, low depth borehole heat exchangers seem to be the most adapted to be installed in old individual houses. However, even if they are associated with a solar ground reloading system, their sizing and costs remain problematic in much cases.
Solar ground reloading associated with GSHP can offer a solution in some particular cases in regions where the sunniness is important ; but this coupling can not be a general solution for the residential retrofit market.
To be valuable in most retrofit cases, GSHP have to be associated with an auxiliary system available during the peak heating load. It is the only way to reduce significantly the ground collectors sizing, and then the installation difficulties and costs.

NOMENCLATURE

L	BHE length	(m)
q	thermal load	(W)
R	effective thermal resistance	(m.K/W)
T	temperature	(°C)
λ	thermal conductivity	(W/m.K)
α	diffusivity	(m^2/day)
ρ	density	(kg/m^3)
G	volumetric loss factor	(W/ m^3.K)

subscripts

g	far field ground
f	brine
y	yearly
m	monthly
h	hourly

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